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FREON

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Technical Bulletin

"FREON" E SERIES FLUOROCARBONS

New stable liquids for uses demanding extraordinary properties and performance characteristics.

APPLICATIONS

Heat Transfer
Electrical Insulation
Optical
Hydraulic
Instrument

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"FREON" PRODUCTS DIVISION

E. I. DU PONT DE NEMOURS & COMPANY (INC.)

WILMINGTON, DELAWARE 19898

"FREON" E SERIES FLUOROCARBONS

A family of five liquids is described in this bulletin. While they differ from each other in certain physical properties, such as volatility and viscosity, they possess in common a number of outstanding, useful characteristics.

Stability	Inert. Stable chemically and thermally (over 500°F). Compatible with plastics, elastomers, and coatings.
Safety	Nonflammable, extremely low order of toxicity, essentially hazard free.
Heat Transfer Characteristics	Ideal for evaporation cooling, providing highest heat flux. Low pumping power requirements for forced convection. Wide liquid ranges - useful at high and low temperatures.
Dielectric Properties	High dielectric strength and resistivity, low losses.
Optical Properties	Colorless, clear and stable through visible and ultraviolet to 2000 Å.
Purity	Sharp boiling points, highly purified, single component* products. No variation in properties, lot to lot, or upon partial evaporation.

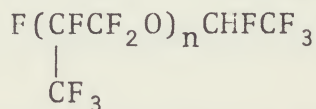
HEAT TRANSFER

"Freon" E fluorocarbons are effective heat transfer fluids for heating and cooling by convection or by evaporative methods.

Forced Convection

"Freon" E fluorocarbons have low pumping power requirements, as they have exceptionally low viscosities, 0.5 to 7.0 cp at 77°F, and high densities, 1.54 to 1.79 g/cc at 77°F. Their wide liquid ranges (see Figure 5) permit operation at high or very low ambient or heat sink temperature. Excellent heat transfer by natural convection is obtained as the high densities of the "Freon" E fluorocarbons provide a good driving force and high rate of mass transfer.

* The chemical structure of the "Freon" E series is:



The E number is equal to n. Mixtures of higher homologs (light oils) are under development. They possess low pour points (<-65°F) as well as low volatility. Descriptive data are available.

Evaporative Cooling

Remarkable improvements in heat transfer are achieved by using volatile coolants which boil at sites where heat removal is required. The heat absorbed by vaporization of liquid in contact with hot surfaces may improve heat transfer coefficients by factors of 10 to 1000 times those obtained with convection systems. Hot spots exposed to "Freon" E fluorocarbons result in localized boiling which provides high heat flux and outstanding control over surface temperatures even though the liquid may be at a considerably higher temperature than would be needed for adequate heat transfer with an oil. The high heat dissipation rates of boiling "Freon" E fluorocarbon can be used in evaporative cooling to markedly increase the power density and life of electronic equipment.

General Considerations

Liquid phase heat transfer is a function of density, specific heat, thermal conductivity, thermal expansion, viscosity of the heat transfer fluid, and system parameters, such as mass rate of flow and system geometry. Given equal system parameters, heat transfer will be improved by fluids having higher density, thermal expansion, specific heat, thermal conductivity, and lower viscosity. The properties of the "Freon" E fluorocarbons of interest in heat transfer are given in Table II and shown in Figures 1 - 6. The relative effectiveness of some coolants and different methods of cooling have been determined as given in the following examples.

Test: 3" x 3" vertical plate, one side cooled.
 Δt between plate and coolant was 20°C.

Coolant and Conditions	Heat Flux Watts/in ²	Relative Effectiveness
Air, free convection	0.04	1
Air, forced convection, 600 ft/min	0.17	4
Silicone 1.6 cp, free convection	0.51	13
"Freon" E 3, forced convection, 180 ft/min	5.9	140
"Freon" E 2, boiling liquid	94.0	2260

DIELECTRIC PROPERTIES

The dielectric properties of the "Freon" E fluorinated ethers make them particularly useful as coolants and insulating liquids in contact with electrical equipment. In general, dielectric strengths are high and dielectric constants and losses are low, with the higher members of the series probably possessing the best combination of electrical properties. Because of their excellent stability, these liquids are suitable for severe conditions of service, such as high temperatures and even occasional sparking.

Dielectric strength of the "Freon" E liquids is high in both the liquid and vapor phases. Liquid phase breakdown voltage for "Freon" E 5 in a 0.1 inch gap between planes is about 49 KV. Values given in Table III for the more volatile members of the series illustrate the high breakdown voltages obtainable in the vapor phase. For pressures of one atmosphere or more, dielectric strength of the vapor is similar to that of the liquids at one atmosphere. Breakdown voltage of a vapor varies with the vapor pressure and hence with liquid temperature, but even at pressures as low as one-third atmosphere (5 psia) "Freon" E vapors have more strength than nitrogen at one atmosphere.

Dielectric constants at frequencies up to 100 kHz range from 2.45 to 3.02. For applications requiring very low dielectric constant, the higher members of the series may be preferable. As is typical of high purity fluorocarbon liquids, dissipation factors of the "Freon" E liquids in the low frequency range are very low (less than 0.00006) and dc resistivities are high (more than 4×10^{14} ohm/cm).

The outstanding stability of the "Freon" E fluorinated ethers is shown not only in their thermal stability and compatibility with materials, but also in their self-healing ability following electrical breakdown. The "Freon" E liquids retain their dielectric strength after repeated sparking under conditions which cause serious degradation and loss of dielectric strength in other types of liquids.

LUBRICANT PROPERTIES

The "Freon" E fluorocarbons are moderately good lubricants; however, because of lowered viscosity at elevated temperatures, care should be taken to avoid overloading bearings. The following results were obtained with "Freon" E 3 in the Shell Four Ball E.P. Test (Federal Test Method 791a Method 6503.1), for a test duration at applied load of 10 seconds.

Applied Load (Kg)	Avg. Scar Diameter (mm)	Load (Kg)
20	0.30	Mean Hertz Load 26.5
25	0.30	
28	0.32	
36	0.34	
40	0.35	Point of Incipient Seizure 56
50	0.37	Weld Point 79
56	0.39	
63	1.92	
71	2.15	
79	WELD	

The Mean Hertz load is calculated from the series of Shell Four Ball scar diameters. The point of incipient seizure is the highest applied load at which the scar diameter indicates that the oil is still functioning in the region of full fluid film lubrication. The scar diameters at loads above this point show the performance of the oil in the area of thin film or boundary lubrication. The weld point is the load at which the four balls weld or at which the scar diameter exceeds 2.5 millimeters.

SOLUBILITY

The solubility of compounds in "Freon" E fluorocarbons decreases with increasing molecular weight of the fluorocarbon, e.g. the solubility of hexane is: "Freon" E 1, miscible; "Freon" E 2, 24% by wt.; "Freon" E 3, 10%; "Freon" E 4, 6%; and "Freon" E 5, 5%. The "Freon" E compounds are less than 1% soluble in oils at 75°F. All of the oils tested were less than 1% soluble in the "Freon" E fluorocarbons. Oxygen containing solvents are moderately soluble in the "Freon" E compounds. Diethyl ether is miscible with the "Freon" E compounds.

STABILITY

The "Freon" E fluorocompounds exhibit a high degree of stability towards chemical or thermal degradation. Tests at elevated temperatures in the presence of many different metals for 30 days resulted in very little effect upon the metals and negligible decomposition of the fluorocarbon. The "Freon" E fluorocarbons may be used continuously at 500°F with most metals and by proper selection of materials the continuous operating temperature may be extended.

COMPATIBILITY WITH MATERIALS

The "Freon" E fluorocarbons exhibit a very high degree of compatibility with a great variety of elastomers, plastics, and wire insulation. The compatibility of materials with "Freon" E 3 is typical of the compatibility of the other members of the "Freon" E series fluorocarbons. Tables IV, V, and VI give the compatibility of "Freon" E 3 with elastomers, plastics, and wire insulation.

TOXICITY

Preliminary toxicity tests with "Freon" E fluorocarbons indicate a very low order of toxicity and essential freedom from toxicity hazard. Acute oral, subacute oral, acute inhalation, subacute inhalation, and skin absorption tests on rats have been carried out to date with "Freon" E 1, "Freon" E 2 and "Freon" E 3, and additional toxicological tests are in progress.

Results of tests will be supplied upon request for use in preparing for applications where substantial exposure of personnel to the liquid, vapor, or mists is possible. In all uses, as with any substance of incompletely defined toxicity, care should be

taken in handling the product and contact should be minimized. At extremely high temperatures the thermal stability of the "Freon" E series fluorocarbons may be exceeded (see page 4) and small amounts of toxic degradation products may be formed. Under such use conditions, adequate ventilation should be provided.

Table I. PROPERTIES OF "FREON" E SERIES FLUOROCARBONS

Property	"Freon" E 1	"Freon" E 2	"Freon" E 3	"Freon" E 4	"Freon" E 5
Formula $F(CFCF_2O)_nCHFCF_3$ CF_3	n=1	n=2	n=3	n=4	n=5
Molecular Weight	286.03	452.08	618.12	784.15	950.18
Boiling Point, °C °F	39.0 102.2	101.0 213.8	153.0 307.4	193.0 379.4	226.0 438.8
Compressibility, % @ 77°F, 500 atm.	8.20	6.48	5.64	5.18	4.85
Crit. Temp., °C °F	157.55 315.59	218.28 424.90	263.17 505.71	295.19 563.34	360.3* 680.5*
Heat of Vaporiza- tion at B.P., cal/g Btu/lb	23.0* 41.4*	17.4* 31.3*	14.5* 26.1*	12.5* 22.5*	11.0* 19.9*
Approx. Pour Point (200,000 cs) °C °F	-154.4 -246.0	-123.3 -190.0	-106.7 -160.0	- 94.4 -138.0	- 83.9 -119.0
Refractive Index, Liquid, 80°F	1.2434	1.2570	1.2654	1.2704	1.2724
Solubility in Water, 77°F, ppm	<25	<25	<25	<25	<25
Solubility of Water, 77°F, ppm	149	103	83	68	-
Solubility of Air in Liquid, 77°F & 1 atm. cc air/100 cc liq	28.0	39.8	36.4	26.6	22.5
Surface Tension, 77°F, dynes/cm	10.4	12.9	14.2	15.2	15.9

* Estimated values

Table II. HEAT TRANSFER PROPERTIES OF LIQUID "FREON" E FLUOROCARBONS
(At 77°F)

Property	"Freon" E 1	"Freon" E 2	"Freon" E 3	"Freon" E 4	"Freon" E 5
Density, g/cc	1.538	1.658	1.723	1.763	1.792
Specific Heat, Cp., Btu/(lb)(°F)	0.245 Est.	0.244	0.243	0.241 Est.	0.240 Est.
Thermal Conductivity Btu/(hr)(ft)(°F)	(0.05)*	(0.05)*	(0.05)*	(0.05)*	(0.05)*
Thermal Expansion, ft ³ /(lb)(°F)	10x10 ⁻⁶	8.5x10 ⁻⁶	6.5x10 ⁻⁶	6x10 ⁻⁶	5.5x10 ⁻⁶
Vapor Pressure, psia @125°F	9.1 23.7	0.59 2.03	0.047 0.23	0.018 0.082	0.004 0.021
Viscosity, centipoise centistoke	0.5 0.3	1.1 0.6	2.2 1.3	4.1 2.3	7.0 3.9

* No experimental values have been determined at this time but a reasonable estimate is felt to be 0.05 Btu/(hr)(ft)(°F).

Table III. DIELECTRIC PROPERTIES OF "FREON" E SERIES LIQUIDS

Property	"Freon" E 1	"Freon" E 2	"Freon" E 3	"Freon" E 4	"Freon" E 5
Breakdown Voltage Liquid, KV (rms) ¹	27.2	34.6	39.5	44.5	49.7
Breakdown Voltage Vapor, KV (rms) ²					
@ 1 atm	22	27	35	-	-
@ 2 atm	38	43	52	-	-
Resistivity ³ , ohm/cm	-	>4x10 ¹⁴	>4x10 ¹⁴	>4x10 ¹⁴	>4x10 ¹⁴
Dielectric Constant κ 100 Hz to 100 kHz	3.02	2.75	2.58	2.50	2.45
Dissipation Factor, Tan δ 100 Hz to 100 kHz	<0.00006	<0.00006	<0.00006	<0.00006	<0.00006

¹ ASTM D 877, 0.1" gap between planes, one atm., 25°C

² Modification of ASTM D 2477, 0.1" gap, sphere to plane

³ ASTM D 257

Table IV. COMPATIBILITY OF
"FREON" E 3 WITH
ELASTOMERS

Elastomer	Test Ratings*	
	Seven Days @ 130°F	Seven Days @ 306°F
"Adiprene" C Urethane Rubber	0	4
"Nordel" Hydrocarbon Rubber	0	2
"Viton" A Fluoro- elastomer	0	1
"Adiprene" L Urethane Rubber	0	2
Nitrile Sili- cone Rubber (NSR-X5602)	0	4
"Thiokol" FA Polysulfide	0	4
"Silastic" 50 Silicone Rubber	0	1
Buna S	0	3
Natural Rubber	0	1
"Hypalon" 40 Synthetic Rubber	1	4
Neoprene W	0	1
Butyl	1	1
Buna N	0	4

*Ratings

- 0 - Suitable for use in contact with liquid dielectric
- 1 - Probably suitable for use
- 2 - Probably not suitable for use
- 3,4 - Not suitable for use

Table V. COMPATIBILITY OF
"FREON" E 3 WITH
PLASTICS

Plastic	Test Ratings*	
	100 hr @130°F	100 hr @306°F
"Alathon 7050 Linear Polyethylene Resin	0	4
"Alathon" 9140 Polypropylene Resin	0	0
"Lucite" Methyl- methacrylate Resin (cast)	0	0
"Zytel" 101 Nylon Resin	0	2
"Teflon" TFE Resin (Type 1)	0	1
"Lexan" Polycarbonate Resin	0	1
"Kralastic" ABS Polymer	0	4
"Styron" 475 Poly- styrene	0	4
Epoxy Resin (G-10-3675)	0	2
Ethyl Cellulose	1	4
"Delrin" Acetal Resin	0	2
Polyvinyl Alcohol	1	2
Polyvinyl Chloride (unplasticized)	0	3

*Ratings

- 0 - Suitable for use in contact with the fluorocarbons
- 1 - Probably suitable for use
- 2 - Probably not suitable for use
- 3 - Not suitable for use
- 4 - Plastic disintegrated or dissolved in the liquid

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"Thiokol", "Silastic", "Kralastic", "Styron" & "Lexan" are registered trademarks.

TABLE VI

COMPATIBILITY OF "FREON" E 3 WITH WIRE COATINGS

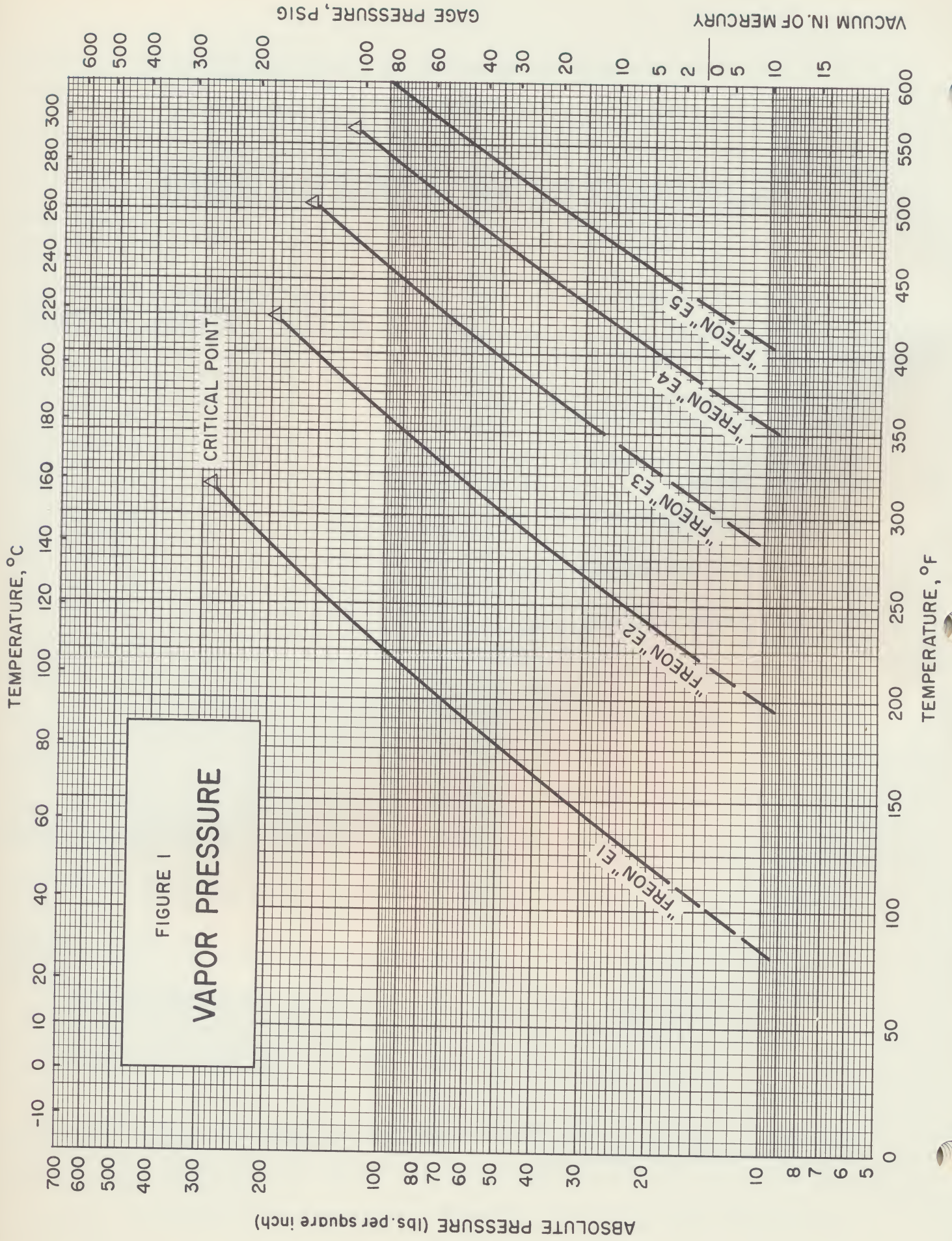
Wire Coating	Test Ratings*	
	100 hrs. at 220°F	100 hrs. at 306°F
"Formvar" polyvinyl formal	1	2
"Anavar" isocyanate-modified polyvinyl formal		0
"Nylclad" nylon-coated polyvinyl formal	1	2
"Acrylex" acrylic		0
"Ensolex" ESX solderable acrylic		0
"Alkanex" terephthalate polyester		0
Enamel "G" polyurethane		0
"Pyre-M.L." polyimide		0
Epoxy		0
Plain enamel (oleoresinous)	0	2

Straight and bent sections of wires (1/4" diameter, bends formed before and after exposure) were tested.

- * Ratings: 0 - No crazing, stress cracking, buckling, and/or temporary softening of coating.
- 1 - Very slight crazing, stress cracking, buckling, and/or temporary softening of coating.
- 2 - Severe crazing, stress cracking, buckling, and/or temporary softening of coating.

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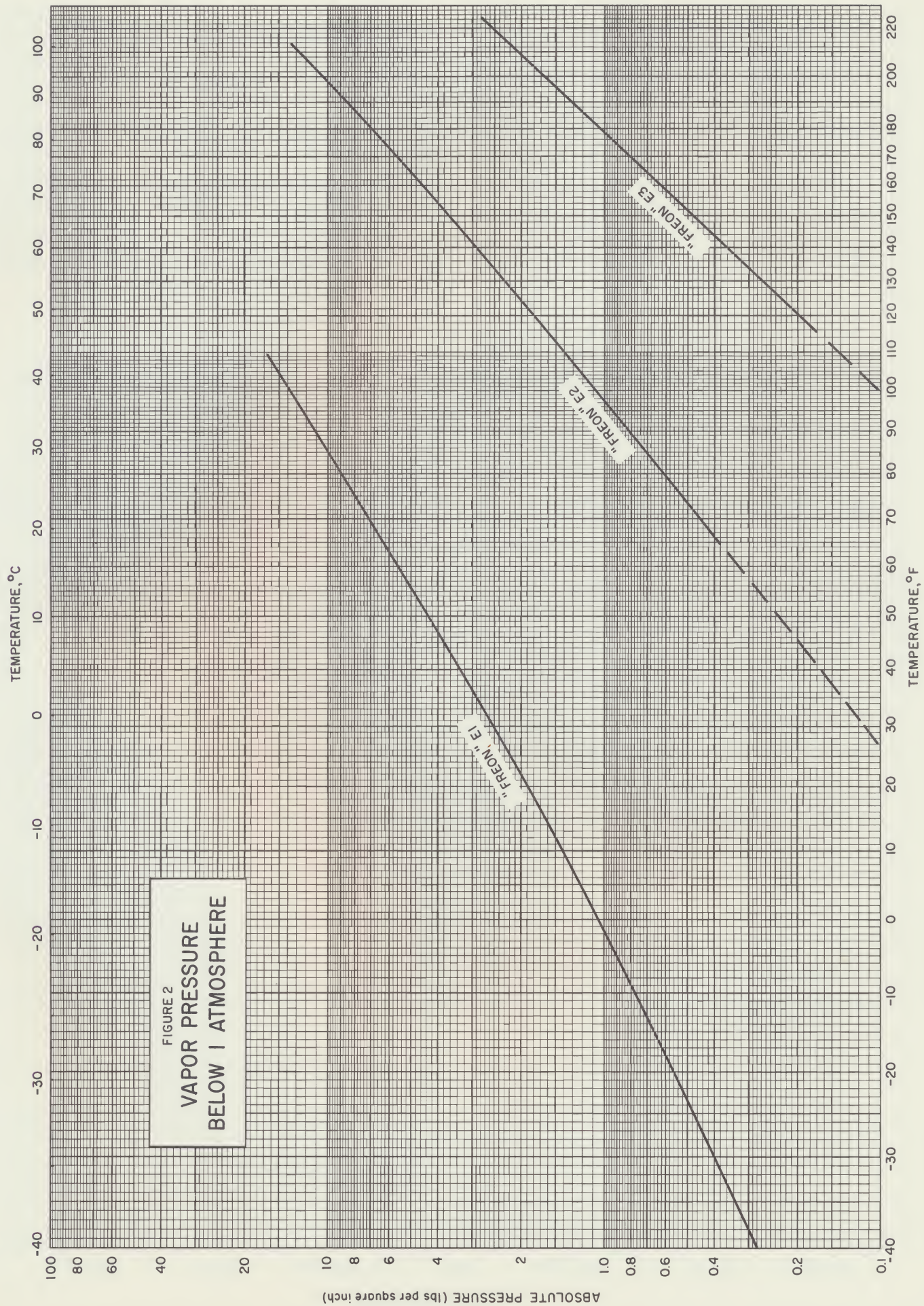
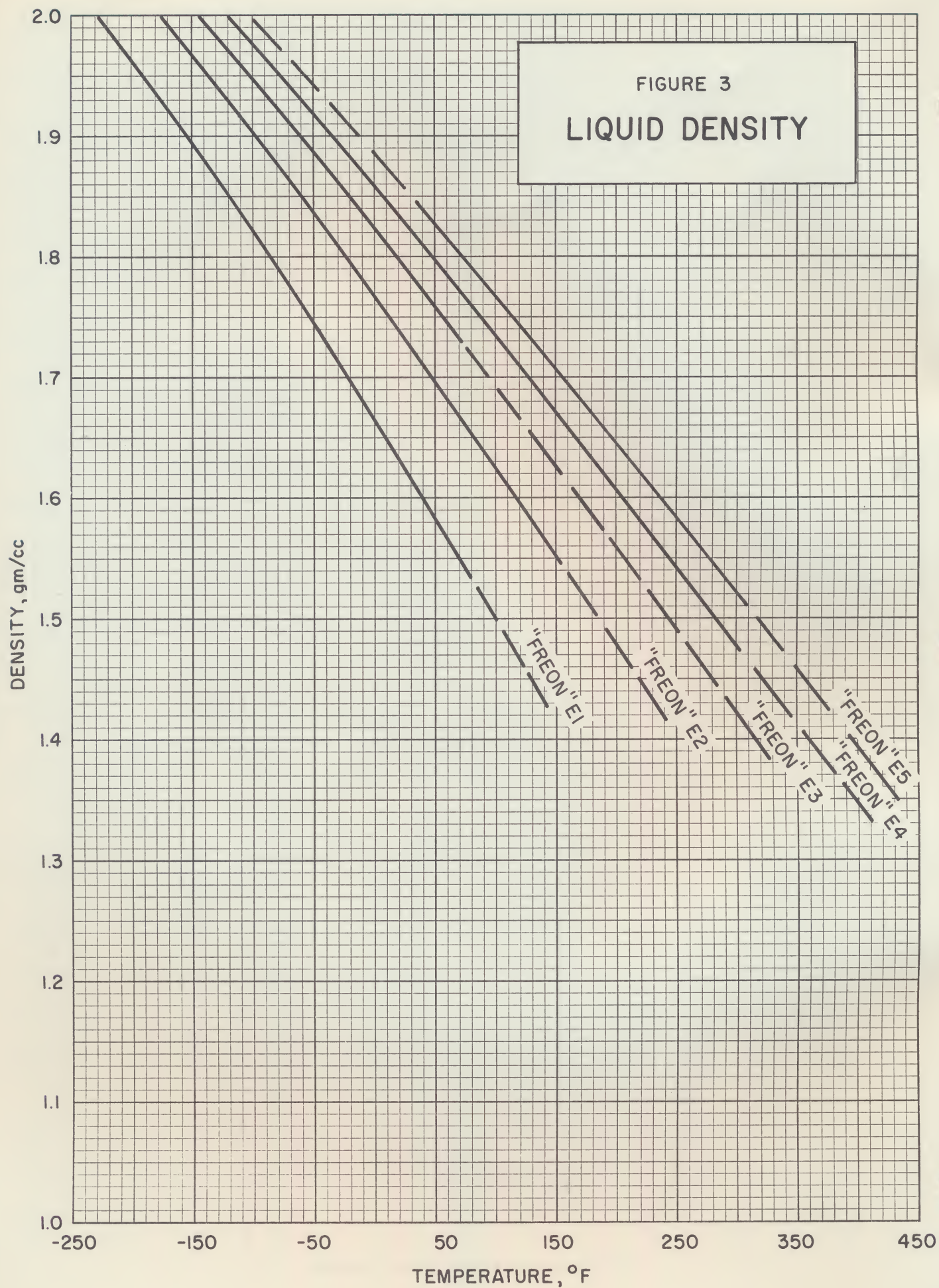


FIGURE 3
LIQUID DENSITY



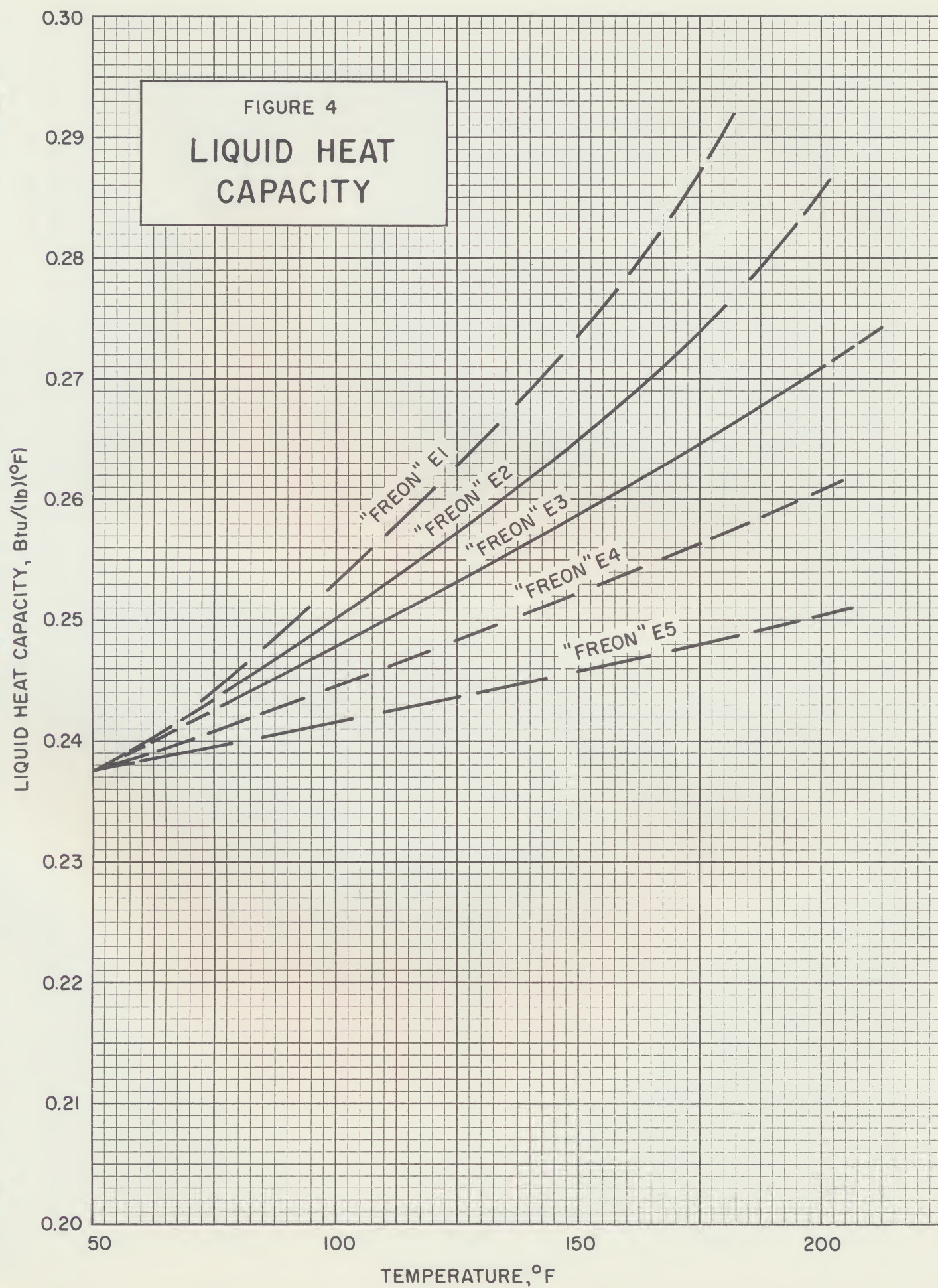


FIGURE 5

LIQUID RANGE OF
"FREON" E SERIES
FLUOROCARBONS

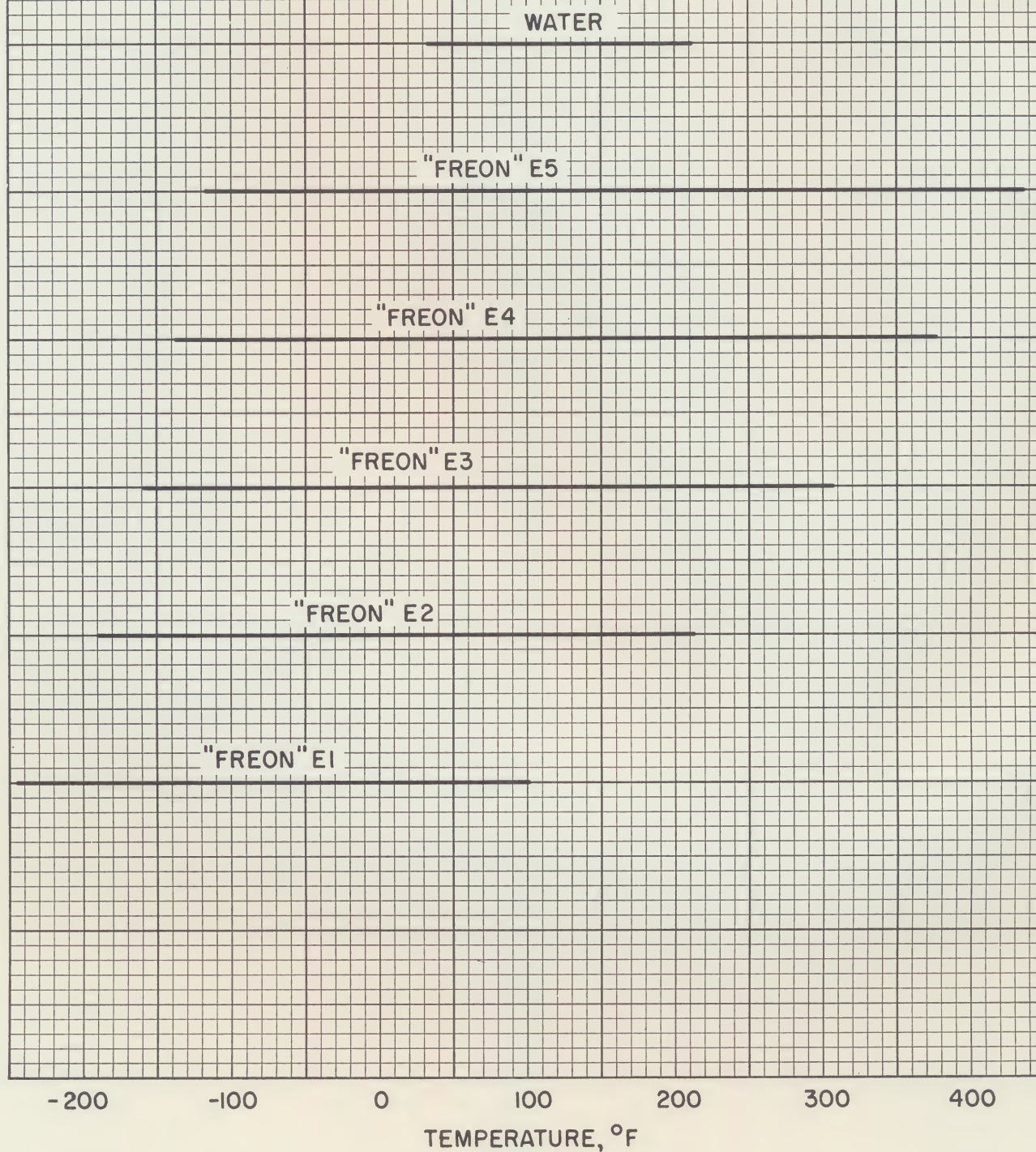
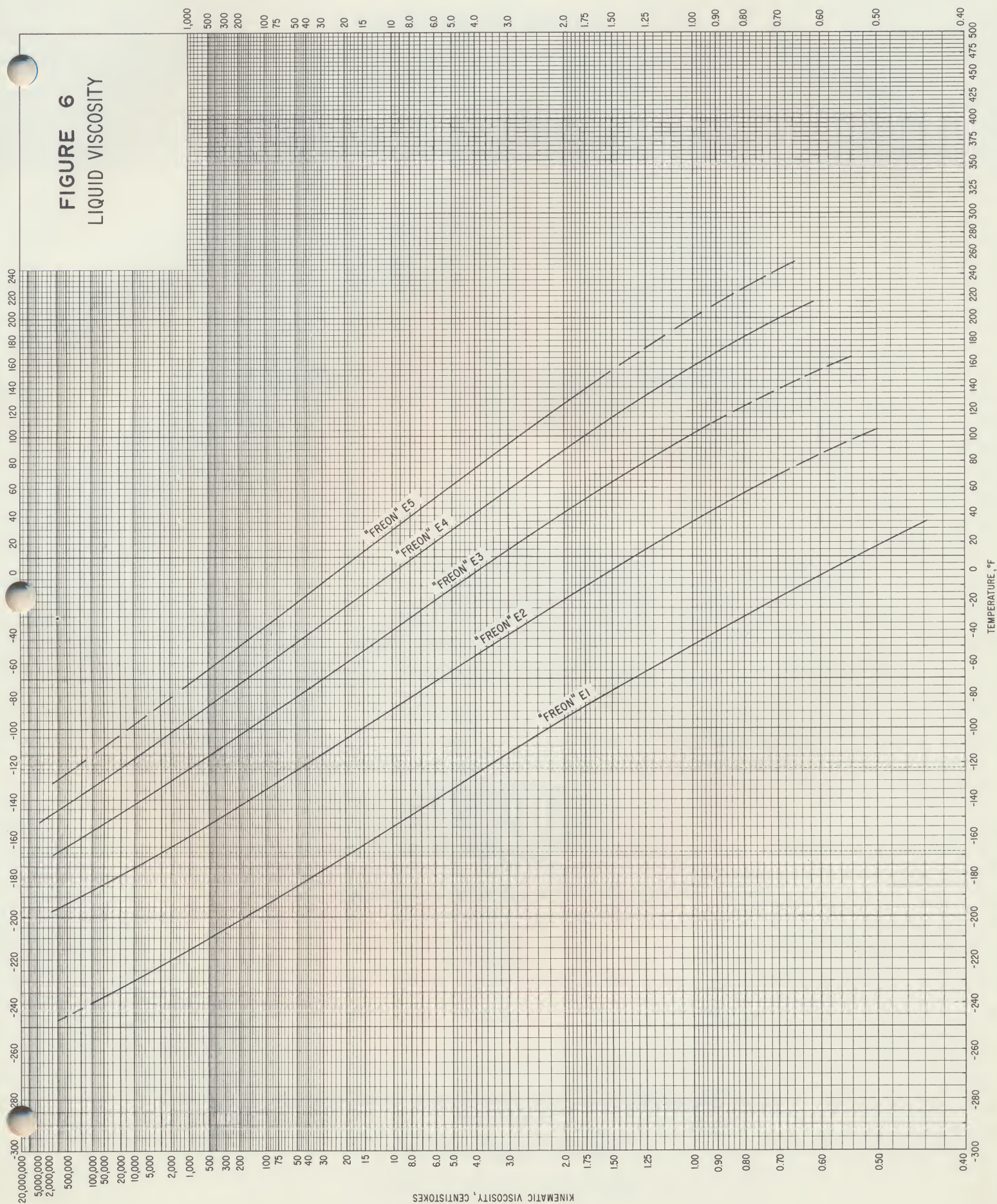


FIGURE 6
LIQUID VISCOSITY



FOR FURTHER INFORMATION

Please contact one of the following district offices:

60 Glenwood Avenue
East Orange, New Jersey 07018
Phone: 676-1112
(Area Code 201)

7 South Dearborn Street
Chicago, Illinois 60603
Phone: 222-5000
(Area Code 312)

701 Welch Road
Palo Alto, California 94304
Phone: 326-2840
(Area Code 415)

712 Main Street
Suite 324
Gulf Building
Houston, Texas 77002
Phone: 222-2468
(Area Code 713)

3503 North Hoyt Street
El Monte, California 91734
Phone: 283-0548
(Area Code 213)

or:

Wilmington, Delaware 19898
Phone: 999-3093
(Area Code 302)

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E. I. DU PONT DE NEMOURS & COMPANY
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"Freon" Products Division
Wilmington, Delaware 19898